Z. Säugetierkunde 57 (1992) 275–287

ISSN 0044-3468

Satellite-linked radio tracking of Atlantic walruses (*Odobenus rosmarus rosmarus*) in northeastern Greenland, 1989–1991

By E. W. Born and L. Ø. Knutsen

Greenland Fisheries Research Institute, Copenhagen, Denmark

Receipt of Ms. 4. 11. 1991
Acceptance of Ms. 26. 3. 1992

Abstract

Determined the feasibility of using satellite telemetry for tracking of walruses in studies of stock identities by attaching a total of 12 satellite transmitters to the tusks of male Atlantic walruses (*Odobenus rosmarus rosmarus*) in Dove Bay (approximately 77° N–20° W), NE Greenland in August 1989 and 1990. In 1989 the Platform Terminal Transmitters (PTT) transmitted for an average of 53 days (SD = 36.3; range: 15–111 days; N = 6). In 1990 four PTTs with similar electronics (two of which had a different antenna design) transmitted for an average of 125 days (SD = 96.9; range: 4–238 days). Two different PTTs worked for 62 and 112 days, respectively. It is indicated that the main reason for premature transmission failure is that the walruses dislodged the units. During August and September 1989 and 1990, all walruses regularly made excursions to the west and southwest up to a distance of about 80 km from their terrestrial haul out site on the northern coast of Dove Bay. During late September and early October the formation of a dense cover of land fast ice forced the walruses off-shore into the Greenland Sea. The instrumented animals moved north to winter in leads and cracks in the pack ice between 80° and 82° N off the coast of NE Greenland.

Introduction

In August 1989 and 1990 satellite transmitters (PTTs = Platform Terminal Transmitters) were attached to Atlantic walruses (*Odobenus rosmarus rosmarus*) in Dove Bay, northeastern Greenland. The objective of the study was to determine the feasibility of using satellite telemetry to track individual walruses and thereby potentially determine stock identities; in this case to elucidate whether a connection exists between stocks in eastern Greenland and in the Svalbard – Franz Josef Land region.

Walruses occur in eastern Greenland between approximately 63° N and approximately 81°15′ N, but their main distribution is north of 70° N. Although it has been suggested that walruses in Northeast Greenland form a relatively small and isolated stock, historical information on observations of walruses in the Greenland Sea and the Fram Strait indicates that a connection exists between walruses in eastern Greenland and at Svalbard further east (Born 1990).

Walruses were first instrumented with satellite transmitters by U.S. Fish and Wildlife Service at Round Island in Alaska during the fall of 1987 (Fancy et al. 1988). In Greenland the only terrestrial walrus haul out sites are found within the borders of the National Park in northeastern Greenland. Because the same individuals occur on the beach several times during the open water season, and also in subsequent years (Born 1990), the remote and undisturbed haul out site at Lille Snenæs (Dove Bay) is an ideal place for testing of satellite transmitters in free ranging walruses.

In this study the satellite-linked radio transmitters used in NE Greenland, and their performance, are described. The movements of the instrumented walruses in Dove Bay and the Greenland Sea in the period August 1989 to late March 1991 are also presented.

U.S. Copyright Clearance Center Code Statement: 0044-3468/92/5705-0275 $ 02.50/0

Material and methods

In the periods 9 to 24 August 1989 and 6 to 19 August 1990, a total of 12 adult male walruses, *Odobenus rosmarus rosmarus* (six in each season) were immobilized by use of etorphine HCl on the beach of Lille Snenæs (76°52′ N, 19°38′ W) on the northern coast of Dove Bay in NE Greenland, and a satellite-linked radio transmitter (PTT) was attached to the tusk of each animal.

The PTTs transmitted via the ARGOS DCLS system (Fancy et al. 1988; Argos 1989; Keating et al. 1990). At 77° N there are about 28 satellite overpasses during each 24 hour period and the total cumulative visibility of the two satellites above the horizon is about 5.5 hours, with maximum satellite coverage employing the longest satellite passes between approximately 12 and 23 GMT (Fancy et al. 1988).

Three types of PTTs differing in shape, material, antenna type and electronics were used. In 1989 and 1990 a total of eight ST-3 PTTs (Telonics, Arizona, USA) with 20 cm long antennas constructed of multistranded stainless steel cable were attached. Two ST-3 PTTs which were similar in shape and material but had a 7 cm long helical antenna were used in 1990 (Fig. 1). Additionally, two T-2028 satellite transmitters manufactured by Toyocom Inc. (Tokyo, Japan) were attached in 1990 (Fig. 2). The antennas of all transmitters used in 1990 were covered along their entire length by a 0.5–1.0 cm thick layer of urethane (Sikaflex 11 FC) to provide strength.

The PTTs had different duty cycles (Tab. 1). The ST-3 PTTs which had a power output of 1 W had repetition rates of 70 and 77. Repetition rate of the T-2028 units was 60; power output was 0.5 W. None of the PTTs transmitted when two external conductivity electrodes (salt water switch, SWS), positioned on the top of the PTT were connected via sea water (i.e. the walrus was submerged).

In addition to providing locations, the ST-3 PTTs also recorded information on external temperature, duration of the previous dive before an uplink, average dive time over the past 24 or 6 hours, respectively, and number of dives (based on closures of the SWS) during the same periods of time. The T-2028 PTTs gave location but had no memory for storing information of the activity of the SWS.

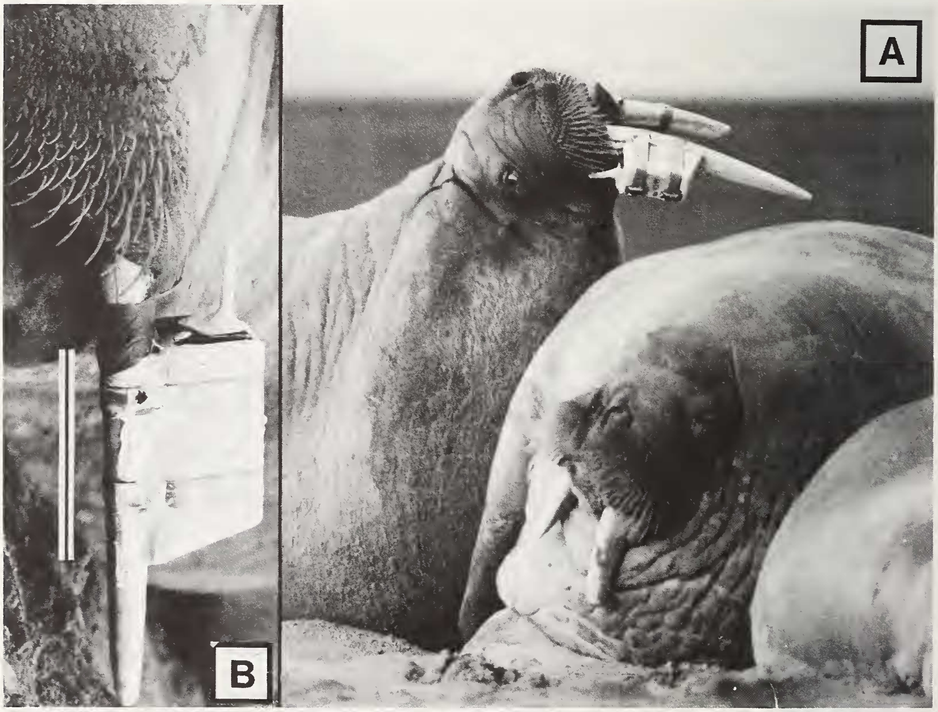

Fig. 1. The ST-3 satellite transmitter with short helical antenna used in 1990 (A); close up view (B); scale = 15 cm. The electronic package and the batteries of the transmitter were encased in a tinned brass housing which was hermetically sealed and backfilled with a polymer material. The housing was covered with urethane rubber to serve as a shock buffer. The unit weighed 1.5 kg

Two 19 mm wide, 316-type stainless steel bandings (Band-It, Houdaille, Denver) were used to attach the unit to the tusk. Grooves were filed in the tusks where these bands would sit, and the lateral surface of the tusk was ground with coarse sandpaper and then cleaned with acetaldehyde. In 1990 polyurethane (Sikaflex 11 FC) was used as a glue between the PTT and the tusk. To ensure that the SWS was out of the water during surfacing, the transmitters were positioned as far up the tusks as possible and somewhat latero-caudally so that they did not protrude in front of the leading edge of the tusks (Figs. 1 and 2). Thereby we hoped to prevent disturbance to the walrus when it was rooting with its vibrissae in the sea floor during feeding. All units were painted with white road paint or fluorescent car paint. Places where the paint was worn off during the field season would reveal sites of physical impact.

Information on ice conditions in the study area was gathered from observations at Lille Snenæs, aerial surveys over Dove Bay during the field periods and extracted from NOAA (thermal infrared) satellite imageries.

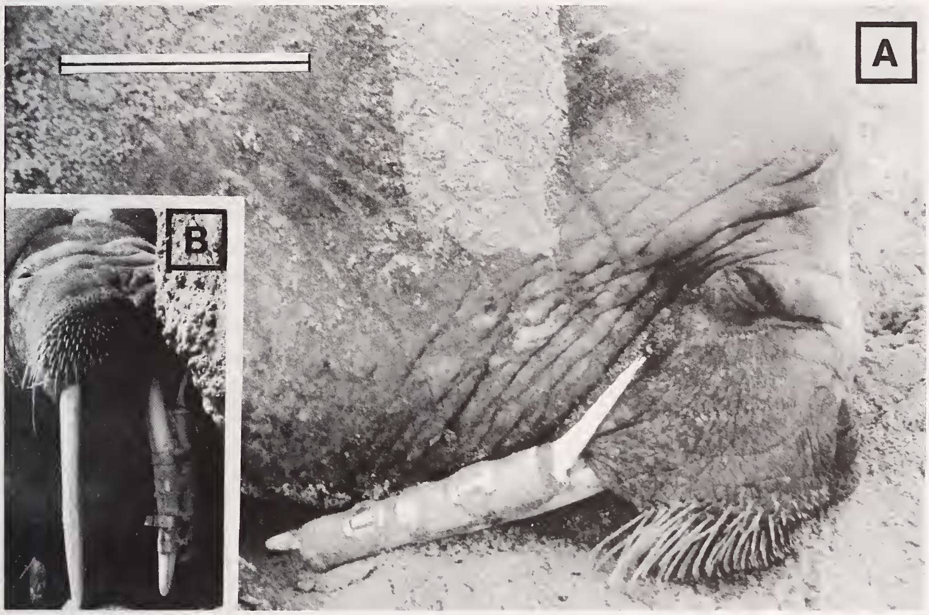

Fig. 2. The T-2028 satellite transmitter used in 1990 (A); close up view (B); scale = 25 cm. The transmitter which weighed 0.305 kg was glued into a stainless steel cylinder with polyurethane and two-component epoxy glue, resulting in a total weight of the unit of 0.750 kg

Treatment of satellite-derived data

Activity of the SWS and temperature sensor data were used to determine whether an instrumented animal was hauled out. The software protocol repeated a qualified dive time until updated with a new dive time. Therefore, when the value for the duration of the 'last dive' was repeated in the data stream the walrus apparently was not swimming (i.e. it was hauled out). The duration of such a haul out period was defined as the time between the first and the last uplink in a sequence of repeated 'last dive' data. An increase in temperature and reception of locations in the best quality classes (NQ = 1–3) during the same period were regarded as supportive evidence that the animal was hauled out.

The precision of the satellite-derived locations was determined for the instrumented walruses when they were observed on the beach of Lille Snenæs. The exact position (+/−30 m) of the haul out site (76° 52′ 53″ N – 19° 38′ 10″ W) was determined from a 1:250 000 topographic map (Greenland Geological Survey) based on aerial photographs and ground control points.

Swimming speed was calculated for instrumented walruses from straight line distances and time between uplinked locations. Only distances with locations of quality NQ = 1–3 are used for this analysis.

Table 1. Performance of satellite transmitters attached on the tusks of Atlantic walruses in NE Greenland in August 1989 and 1990

Year	PTT ID number/ type	Duty cycle	Expected lifetime[a] (days)	Date of instrumentation (Aug.)	Date of last uplink (day/month/year)	No. of days active	% of expected lifetime
1989	4344/ST-3	Continuous	90+	9	23 Aug. 89	15	17
	4345/ST-3	Continuous	90+	12	30 Nov. 89	111	123
	4347/ST-3	24 h on/24 h off	180+	13	29 Oct. 89	78[b]	43
	1858/ST-3	1 week on/1 week off	180+	14	2 Oct. 89	50	28
	1856/ST-3	1 week on/1 week off	180+	19	1 Oct. 89	46[c]	26
	1859/ST-3	1 week on/1 week off	180+	24	12 Sep. 89	20	11
1990	4348/ST-3	Continuous	90+	6	23 Nov. 90	110	122
	4346/ST-3[1]	1 week on/1 week off	180+	7	10 Aug. 90	4	2
	4349/ST-3	Continuous	90+	8	2 Apr. 91	238	264
	1857/ST-3	1 week on/1 week off	180+	19	13 Jan. 91	148	82
	3985/T-2028	1 day on/3 d off	160+	11	11 Oct 90	62	39
	3984/T-2028	1 day on/3 d off	160+	12	1 Dec. 90	112	70

[a] not including prolongation of life time due to function of the salt water switch. – [b] reliable data for 22 consecutive days, then pause until a single string of sensor data was received on 29 October. – [c] reliable data stream until 9 September then pause until 1 October when a single string of sensor data was transmitted. – [1] this animal bent the antenna and apparently damaged it.

Results

During the field periods, when the instrumented animals were observed several times on the beach after feeding excursions, all PTTs stayed in position on the tusks. We saw no attempts to remove the PTTs, and apparently the animals paid little attention to the presence of the units. Apart from being less vulnerable to wear, the short helical antenna on two of the ST-3 units used in 1990 could not touch the lateral vibrissae and therefore was not able to disturb the animal. During the field season the paint on the somewhat bulky ST-3 PTTs was gradually worn off. The wear began on the frontal side, probably indicating that the units were in contact with the substrate during feeding. Signs of wear were not observed on the more elongate and slender T-2028 units.

During August 1990, five of the six walruses which were instrumented in August 1989 were recognized and subsequently seen on the beach several times during the field period. Walrus no. 4345, which transmitted for 111 days in 1989, still had the 1989 PTT in situ whereas the other animal had lost their transmitters. Walrus no. 4345 was immobilized again on 8 August 1990 and provided with a new PTT (no. 4349; Tab. 1). On 28 and 29 August 1991 this walrus was observed on Lille Snenæs with the 1990-PTT intact on the tusk. On the same dates walrus no. 3985 was observed with the T-2028 PTT attached in 1990 on the tusk. The antenna of this unit was broken off. Another animal (ID no. ?) instrumented in 1990 was identified on the beach without the PTT (Søder, pers. comm.).

The PTTs transmitted between 4 and 238 days after attachment (Tab. 1). In the following analyses PTT no. 4346 (1990) is omitted. It only transmitted for the first four days after attachment while the walrus was hauled out on the beach and is therefore considered not to be representative. On average the ST-3 PTTs attached in 1990 functioned three times longer than those used in 1989 (1989): $\bar{x}$ = 53 days, SD = 36.3, N = 6; 1990: $\bar{x}$ = 165 days, SD = 65.7, N = 3; d = 2.749; $P < 0.05$).

During August and September, when the walruses occurred inshore and hauled out on land and ice, at least one location was obtained from the ST-3 transmitters on an average of 77 % (range: 25 % to 100 %) of the PTT-days (i.e. days where the PTT was in the 'on duty' mode). When the walruses moved offshore after September, the number of locations decreased and at least one location was obtained on an average of only 33 % of the PTT-days (range: 14–58 %) during the remaining period. During August–September the two T-2028 PTTs gave at least one location on an average of 32 % of the PTT-days. The corresponding value for the period October–December was 35 %.

This shift in distribution of instrumented animals following a decrease in temperature and formation of land fast ice in Dove Bay, was also reflected in the location-performance index of all transmitters (i.e. number of locations per PTT-day; Tab. 2). The index for

Table 2. **Location-performance index (locations · PTT-day^{-1}) as unweighted averages for two different periods in 1989 and 1990**

(i.e. inshore period in August and September, and offshore period from October until transmission stop)

Year	PTT-type/N	August–September Index (SD) (PTTs[a])	October–onwards Index (SD) (PTTs)
1989	ST-3/6	7.77 (2.37) (6)	5.49 (3.56) (2)
1990	ST-3/3[b]	2.96 (1.22) (3)	1.25 (0.74) (3)
	T-2028/2	1.67 (0.92) (2)	1.05 (0.39) (2)

[a] no. of active PTTs included in the analysis. – [b] no. 4346 which only transmitted for 4 days at the beach was omitted.

August-Steptember for the ST-3 PTTs attached in 1990 was significantly lower than that obtained for the same type of transmitters in 1989 (d = 2.749; $P < 0.05$). This was also the case during October and later months (d = 4.018; $P < 0.05$; Tab. 2). The low location-performance indices obtained from the T-2028 PTTs during both periods in 1990 were not significantly different from those from the 1990 ST-3 transmitters.

Overall, between 60.3 % and 76.6 % of all locations received from the different PTTs were of the least precise category (NQ = 0; Tab. 3). The ST-3 PTTs with short antennas apparently gave relatively more locations in the least precise category (NQ = 0) than the other two types of PTT (Tab. 3). However, this difference was not statistically assured ($P > 0.05$, $X^2 = 12.521$, df = 9).

The number of locations received, and their quality, was to a large extent influenced by the behaviour of the walruses, and in particularly by whether they were in the water or were hauled out on ice or land. The time that instrumented animals hauled out on the beach of Lille Snenæs, as determined by SWS activity, was on average 0.65 h later (SD = 0.95; range: 0.05–2.43 h; N = 6) than actual time determined from direct observations. On average, the recorded time of entering the water was 1.37 h (SD = 1.50; range: 0.05–5.10 h; N = 16) late in comparison with direct observations. Thus, the activity of the SWS can be used to roughly determine haul out activity. For walruses instrumented with ST-3 PTTs a location-performance index was determined for three "behavioural

Table 3. **Distribution of locations in four categories of precision (NQ = 0–3) for three different types of PTTs**

Year	PTT-type/No. of PTTs	No. of locations	% of locations in four different quality classes NQ = 0	1	2	3
1989	ST-3 long antenna/6	1251	60.3	21.4	16.6	1.7
1990	ST-3 long antenna/2	254	60.6	26.8	11.8	0.8
	ST-3 short antenna/2	459	76.6	17.0	5.7	0.7
	T-2028 long antenna/2	56	62.5	26.8	8.9	1.8

categories": 1. in water, 2. hauled out on land, and 3. hauled out on ice. In both seasons, and for all three substrates, there was a tendency for the number of locations per hour to decrease during the period. These trends were, however, not statistically significant and the data were therefore pooled for the two years (Tab. 4). The location-performance index for animals on ice was higher than for animals which hauled out on land. A relatively larger fraction of the locations was of the least precise category (NQ = 0) when the animals were in the water (Tab. 4). Although the location-performance indices of the two "short antenna" PTTs were lower than those obtained from the eight 'long-antenna' ST-3 PTTs, the differences were not statistically significant ($P > 0.05$).

Table 4. **Location-performance index (locations · PTT–h^{-1}) for three different 'substrates' for ST-3 PTTs on walruses during August–November 1989 and August–December 1990**

Year/ No. PTTs	Substrate	Time surveyed[a] (h)	Location-performance index (loc./h)	% of locations in four quality classes (NQ = 0–3) 0	1	2	3
1989/6	Water	3234.56	0.135	89.5	8.6	1.9	0
	Land	649.77	0.580	49.1	28.4	19.1	3.4
	Ice	675.57	0.660	40.8	29.2	28.5	1.5
1990/4	Water	2781.52	0.056	98.0	0.7	1.3	0
	Land	739.40	0.367	56.8	28.8	13.2	1.2
	Ice	342.67	0.391	50.0	38.1	11.2	0.8

[a] during the period a variable number of PTTs with different duty cycles were monitored.

The satellite-derived locations (NQ = 1–3) of walruses hauled out on Lille Snenæs were somewhat less precise than specified by the system (Tab. 5). On average, the locations in the least accurate category (NQ = 0) were between 10 and 12 km off Lille Snenæs.

Satellite derived information on travelling speed indicates that average swimming speed was 4.0 km/h (SD = 4.03). In this study a maximum travelling speed of 16.7 km/h was recorded (Tab. 6).

Movements

Satellite derived information on movements revealed that during August and the first half of September 1989 and 1990, all instrumented walruses made excursions from the beach of Lille Snenæs, to the shallow water areas in the western and southwestern parts of Dove Bay (Fig. 3). Locations in the best quality classes indicate that maximum distance from Lille Snenæs of such excursions was about 80 km. Due to the absence of ice in Dove Bay in August and September 1990, the animals were not able to haul out on ice floes during their feeding excursion. For that reason substantially fewer off-shore locations were obtained in 1990, and hence the walruses movements could not be followed in similar detail.

Table 5. **Precision of locations for three different types of PTTs on walruses which hauled out on the beach of Lille Snenæs (Dove Bay, NE Greenland) in August 1989 and 1990**

PTTtype	Precision (km) of locations in four location classes			
	NQ = 0 Mean (SD) (range) N	1 Mean (SD) (range) N	2 Mean (SD) (range) N	3 Mean (SD) (range) N
ST-3 Long antenna (N = 8)	12.374 (26.501) (0.114–170.690) 90	0.935 (0.861) (0.134–4.276) 51	1.364 (1.197) (0.114–5.428) 31	0.795 (0.035) (0.764–0.832) 3
ST-3 Short antenna (N = 2)	10.211 (15.633) (0.300–84.959) 43	1.131 (1.142) (0.450–4.581) 19	1.089 (0.786) (0.101–2.387) 11	1.101 (–) (0.444–2.203) 2
T-2028 (N = 2)	– – –	0.748 (0.422) (0.447–1.231) 3	– – –	1.034 (–) – 1

Table 6. **Satellite derived information on walrus swimming speed**

Year	Animal ID	Swimming speed (km/h)				
		Mean	SD	Min.	Max.	N
1989	1856	0.75	0.54	0.32	1.51	4
	1858	3.20	2.93	0.44	8.45	14
	4344	4.56	4.23	0.90	14.99	10
	4345	2.35	0.59	1.68	2.76	3
	4347	9.22	4.39	4.53	16.74	6
1990	3985	0.76	–	–	–	1
	1857	0.72	–	–	–	1
Total		4.03	4.03	0.32	16.74	39

In 1989 the last location from Lille Snenæs was obtained from walrus no. 4345 on 19 September. The two animals (no. 1858 and no. 4345) which still had units which transmitted after the first half of September progressively moved south in Dove Bay during the second half of September. Presumably this happened as a response to fast ice being formed in the bay. Walrus no. 4345 spent some time at the shallow water banks at Påskenæsset and at the southwestern shore of Store Koldewey before moving offshore into the Greenland Sea around 17 October (Fig. 4). The locations in the best quality class (NQ = 3) from the shores near Påskenæsset and on the southwestern coast of Store Koldewey indicate that no. 4345 hauled out on land on these locations. During the second half of October and until 29 November, when the last location was received in 1989, walrus no. 4345 occurred off-shore in the Greenland Sea south to a straight line distance of about 430 km from Lille Snenæs (Fig. 4). Locations were obtained from the shear zone between the very dense pack ice over the continental shelf and the more active and loose pack ice further east overlying deeper waters. At the beginning of November the walrus made an excursion to the shallow water ground at the southern shore of Shannon where there was a polynya in 1989. When transmissions ceased at the end of November, walrus no. 4345 had moved northwards against the East Greenland Current to a shallow water bank.

In 1990 the walruses were able to haul out on Lille Snenæs until the beginning of October. The last location from the beach was received from walrus no. 4348 on 5 October 1990. During the first half of October 1990 the walruses were forced by the formation of a

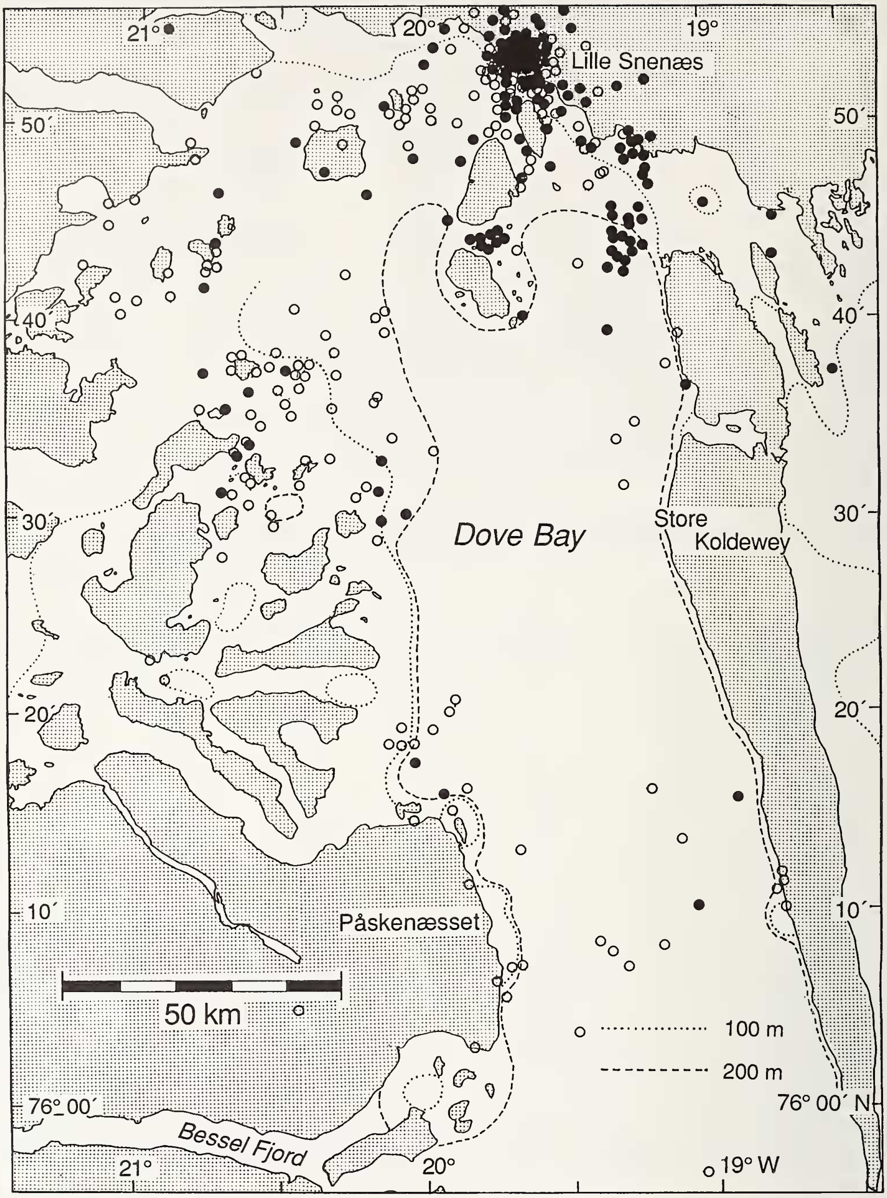

Fig. 3. Locations (NQ = 0–3) received between 6 August and 18 October 1989 (○) and 1990 (●) from a total of 12 male walruses instrumented with satellite transmitters. All locations south of 76° 20′ N were from after 29 September. For days where only locations in the least accurate category (NQ = 0) were obtained, an average location calculated on basis of all locations received during that 24 h period is given as a single point in the Figs. 3–5

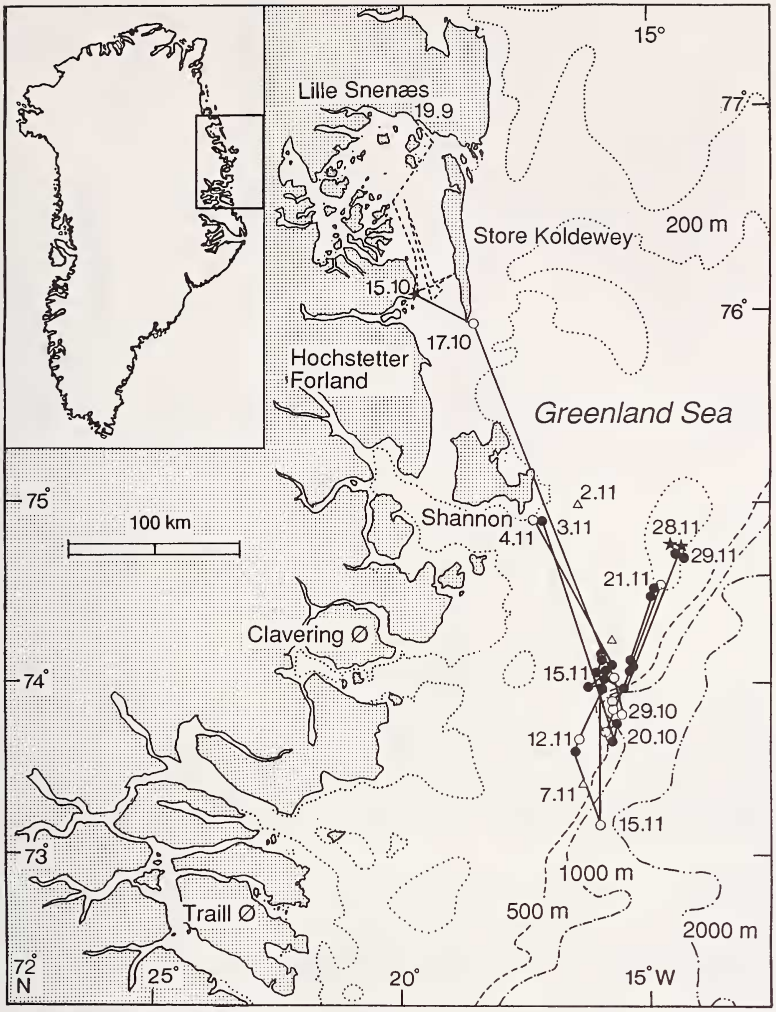

Fig. 4. Movements of walrus "N" (no. 4345) in the Greenland Sea between mid-October and late November 1989. ★ = NQ = 3; ● = 2; ○ = 1; △ = 0, (15.10 = day and month)

dense cover of land fast ice in Dove Bay to retreat offshore into the Greenland Sea (Fig. 5). This emigration occurred both through the straits north and south of the island of Store Koldewey. During the fall migration in 1990 walrus no. 4349 followed more or less the same route as in 1989. In October and November 1990 the instrumented walruses moved north in the Greenland Sea, against the direction of the East Greenland Current. They occurred in the shear zone between the dense land fast ice and the more dynamic pack ice to the east. This zone lies over the edge of the shallow water banks of the continental shelf. On 16 November 1990 walrus no. 4348 occurred at 82° 15′ N and 6° 33′ W (Fig. 5). However, this position represents an average of three locations in the least precise category ranging between 80° 36′–83° 42′ N and 4° 23′–9° 02′ W. The last location from no. 4349 was received on 27 March 1991 (Fig. 5).

The study showed that walruses winter in leads and cracks in the dense pack ice off the coast of NE Greenland and in the polynya off Nordostrundingen ('The Northeast Water').

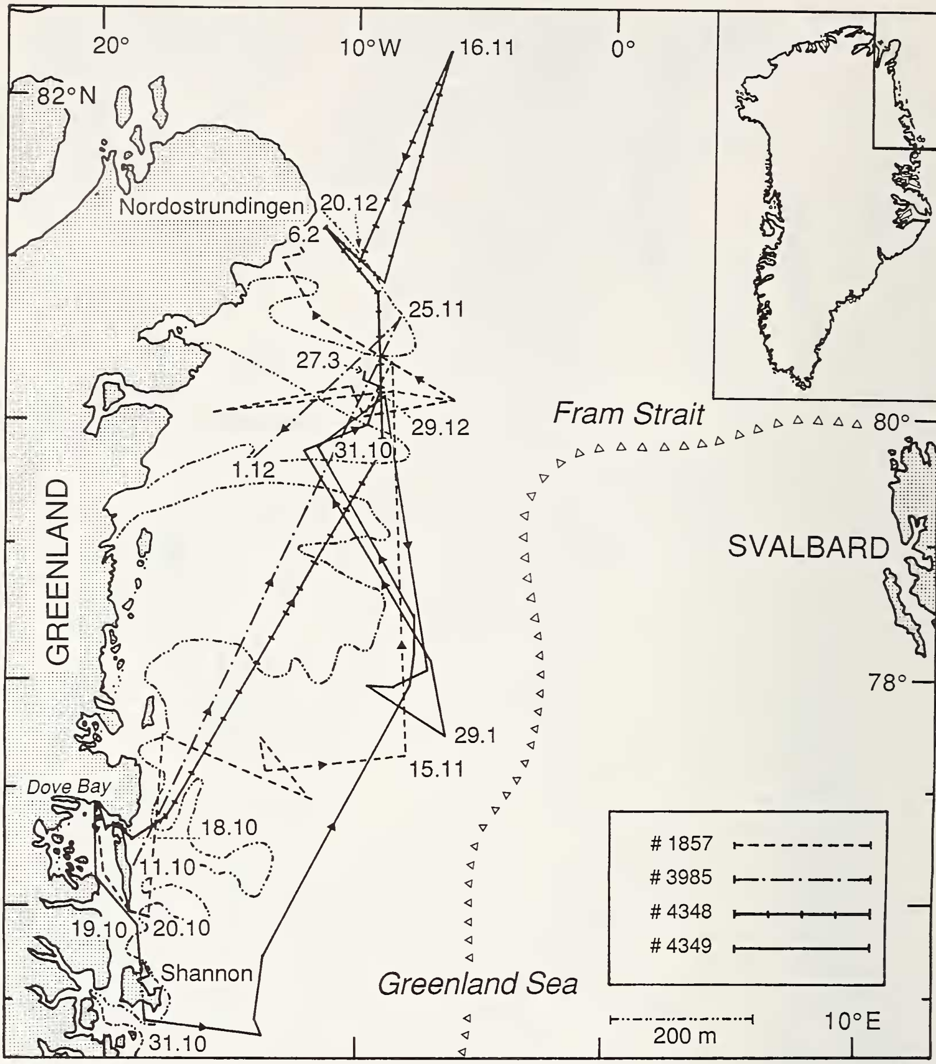

Fig. 5. Movements in the Greenland Sea of four walruses which transmitted after mid-October 1990. △: edge of pack ice late March 1991

Based on tracking of admittedly few animals it is indicated that the group of walruses occurring in eastern Greenland is separate from walruses in the Svalbard and the Franz Josef Land areas further east.

Discussion

Observations at Lille Snenæs indicate that the weight and the shape of the ST-3 PTTs attached to the tusks apparently did not affect the walruses. The ST-3 units represented only about 0.2 % of estimated total body weight of the instrumented animals and 4 to 5 % of the weight of the head (Born, unpubl. data). However, the somewhat bulky configuration of this PTT and the unprotected and lateral position of the 20 cm whip antenna apparently caused premature transmission failure in some cases. Transmission failure due to breakage or manipulation of the long version of the ST-3 antenna was observed in 1989 and 1990. Loss of the unit after we had left the study area may have caused the transmissions to stop in other cases. This is supported by the finding that walrus no. 4345 (= no. 4349 in 1990), which transmitted for 111 days in 1989 and 238 days in 1990–1991, still had the unit attached when it reappeared at Lille Snenæs in August 1990 and 1991, respectively; and that walrus no. 3984, which transmitted for 112 days in 1990, also had the T-2028 PTT in August 1991 whereas all others had lost their unit. Evidently, the short antenna was superior in that it was not able to touch the vibrissae, which are very sensitive (Kastelein and Gaalen 1988) and thereby motivate the walruses to dislodge the unit. The fact that no wear was observed on the T-2028 PTTs attached in 1990 confirmed our suspicion that the use of smaller and more elongated PTTs is desirable, in particular for the tracking of subadults or female walruses which have slender tusks.

Comparatively more off-shore locations were received during August–September 1989 than in 1990. This is due to a difference in ice conditions in Dove Bay during the two seasons. The availability of suitable ice for hauling out influences walrus behaviour and hence the results of the telemetry. During the field period in 1989 (29 July to 25 August) the central and deeper parts of Dove Bay were 9/10 covered with a sheet of old fast ice whereas the shallow water area in the western part of the bays was 1–5/10 ice covered. In 1990 the sheet of 6–8/10 fast ice which covered the central parts of Dove Bay by 29 July broke up between 6 and 10 August and was swept away by strong winds coming from the west. Thereafter there were no ice floes for hauling out in the area.

The number of locations received per hour was greater for animals on ice than for animals on land. This is presumably because walruses hauling out on land spent proportionally more time doing so during night and early morning than those animals which hauled out on ice (Born, unpubl. data). Hence, walruses on land spend proportionately more time hauled out during periods with reduced satellite coverage and when satellite overpasses occur at low angles. In contrast, walruses which were on ice preferably hauled out during afternoon and evening when there is better satellite coverage. In some cases the 400 to 800 m high mountains in the surrounding of Lille Snenæs may have blocked transmissions during some satellite passes.

Walruses on ice produced a greater proportion of higher quality locations than those on land. Presumably this is due to the combined effect of a difference in diurnal haul out rhythm, as indicated above, and the VSWR (voltage standing wave ratio) effect. When placed on an animal the performance of a PTT is reduced due to the proximity of the antenna to the animal's body and the resulting effect of the VSWR. The result of the VSWR effect is a reduction in effective radiated power from the antenna because of detuning and pattern lobing due to the antenna's close proximity to a large conductive mass (Fancy et al. 1988). We suspect that the VSWR effect may be relatively large for PTTs that are attached to walruses where the antenna is close to the massive and often moist head of the animal. The comparatively poor location-performance index for walruses which were hauled out on land can partly be explained by the VSWR effect also originating from the antenna being in close proximity to the bodies of other walruses. Observations made from Lille Snenæs showed that walruses which hauled out on ice were either single or in groups of only two or three individuals (Born, unpubl. data).

The greater location-performance index of the ST-3 PTTs in comparison with the T-2028 PTTs can likely be ascribed to the greater power output of the ST-3 transmitters.

Our findings are very similar to those reported by Stewart et al. (1989) who in a study of free ranging harbour seals (*Phoca vitulina richardi*), found that about 60 % of the locations obtained at sea were of poorer quality (NQ = 0) and that the overall accuracy of NQ = 0 locations was about 15 km. Satellite-derived locations obtained for walruses at Lille Snenæs were somewhat less accurate than specified by the system. A similar discrepancy was also experienced in a study of white whales (*Delphinapterus leucas*) by MARTIN and SMITH (1989) and by STEWART et al. (1989) in harbour seals.

As pointed out by STEWART et al. (1989) the fact that fewer locations are obtained from diving animals makes it likely that locations from feeding areas are under represented. Direct observations showed that walruses which apparently were feeding spent about 85 % of the time submerged (BORN 1992). Only few locations can therefore be expected from feeding walruses when they do not have an opportunity to haul out on ice between feeding bouts. This was confirmed when very few locations were obtained from walruses offshore during August and September 1990 when there was no ice in Dove Bay. This was in contrast to 1989 when several locations were obtained from walruses which hauled out on ice at the shallow banks in Dove Bay. Walruses feed on bottom dwelling molluscs (e.g. FAY 1982; FAY and BURNS 1988) and must theoretically dive for between 6 and 16 hours per day to meet their daily food requirement. They therefore spend a lot of time at the mollusc banks and the probability of identifying such feeding areas via a relatively large number of locations is greater than in seals which feed pelagically. We believe that the stenophagous feeding behaviour of the walrus allows satellite telemetry to be used for the identification of feeding areas and perhaps also of other areas of ecological importance (e.g. mating areas) in this species.

Satellite derived information on travelling speeds obtained in our study is consistent with other published data. According to FAY (1982) the normal swimming speed of walruses is up to 10 km/h. FAY (1981) states that normal cruising speed is about 7 km/h while the maximum "spring" speed is at least 35 km/h.

Our study indicates that the walruses migrate into Dove Bay during the open water season for two purposes: 1. to feed intensively on the molluscs banks, and 2. to haul out on land at Lille Snenæs between feeding excursions to moult.

From tracking a relatively low number of walruses we tentatively conclude that: 1. satellite telemetry is a suitable method for studying spatial and behavioural ecology of walruses, 2. walruses can winter in small groups in leads and cracks along the coast of NE Greenland in areas with shallow water and 3. a separate stock of walruses may occur in these areas.

Acknowledgements

This study was financed by a research grant from Aage V. Jensens Foundation. The logistic support received from Greenland Environmental Research Institute, Greenland Fisheries Research Institute and Greenland Geological Survey is greatly acknowledged. We are particularly grateful for the help and encouragement that we received during various phases of this study from S. HILLS (U.S. Fish and Wildlife Service, Alaska), S. TOMKIEWICZ (Telonics) and M. HASEGAWA (Toyocom). RENÉ SØDER is thanked for providing us with information on walruses at Lille Snenæs in 1991. We wish to thank Drs. A. R. MARTIN (Sea Mammal Research Unit, British Antarctic Survey, Cambridge), S. TOMKIEWICZ and S. HILLS for their constructive criticism to an early draft.

Zusammenfassung

Satelliten-gestützte Telemetrie an Atlantik-Walrossen (Odobenus rosmarus rosmarus) von 1989 bis 1991 im Nordosten Grönlands

Um die Anwendbarkeit von Satelliten-Telemetrie für Studien des Bestandes von Walrossen zu klären, wurden im August 1989 und 1990 insgesamt 12 satellitengestützte Sender an den Stoßzähnen von ausgewachsenen, männlichen Atlantik-Walrossen (*Odobenus rosmarus rosmarus*) angebracht. Die Walrosse befanden sich in der Dove Bucht (77° N–20° W) in NO Grönland. 1989 funktionierten die Sender durchschnittlich an 53 Tagen (min.-max.: 15–111 Tage; N = 6), 1990 vier Sender mit ähnlicher elektronischer Ausstattung im Durchschnitt 125 Tage (min.-max.: 4–238 Tage). Jedoch hatten zwei dieser Sender ein anderes Antennendesign. Die zwei Sender des anderen Fabrikates arbeiteten an 62 bzw. 112 Tagen. Der frühzeitige Transmissionsabbruch ist sehr wahrscheinlich dadurch begründet, daß die Walrosse die Sender zerstört und entfernt hatten. Im August und September 1989 und 1990 unternahmen die mit Sendern versehenen Tiere Exkursionen innerhalb der Dove Bucht, und zwar in

einem Abstand bis zu 80 km von dem Platz, an dem sie an Land gegangen sind an der Nordküste der Bucht. Im Laufe des September/Oktober zwang eine neue, dichte Eisschicht in der Dove Bucht die Walrosse dazu, sich nach Osten ins Grönländische Meer zu begeben. Danach strebten sie in Richtung Norden, wo sie in Spalten im dichten Packeis zwischen 80° N und 82° N vor der nordostgrönländischen Küste überwintern.

References

ARGOS (1989): Guide to ARGOS system, September 1989. Toulouse, France: CLS ARGOS.

BORN, E. W. (1990): Distribution and abundance of Atlantic walrus (*Odobenus rosmarus rosmarus*) in Greenland. In: The Ecology and Management of Walrus Populations: Report of an International Workshop. Ed. by F. H. FAY, B. P. KELLY, and B. A. FAY. Washington, DC: U.S. Marine Mammal Commission. 95–153.

— (1992): *Odobenus rosmarus* Linnaeus, 1758 – Walross. In: Handbuch der Säugetiere Europas. Meeressäuger. Teil III: Robben. Ed. by R. DUGUY and D. ROBINEAU. Wiesbaden: AULA-Verlag. pp. 269–299.

FANCY, S. G.; PANK, L. F.; DOUGLAS, D. C.; CURBY, C. H.; GARNER, G. W.; AMSTRUP, S. C.; REGELIN, W. L. (1988): Satellite Telemetry: A New Tool for Wildlife Research and Management. U.S. Fish and Wildlife Service Resource Publ. **172**, 1–54.

FAY, F. H. (1981): Walrus *Odobenus rosmarus* (Linnaeus, 1758). In: Handbook of Marine Mammals. Vol. 1. The Walrus, Sea Lions, Fur Seals and Sea Otter. Ed. by S. H. RIDGWAY and R. J. HARRISON. London: Academic Press. pp. 1–23.

— (1982): Ecology and Biology of the Pacific Walrus, *Odobenus rosmarus divergens* Illiger. North American Fauna **74**, 1–279.

FAY, F. H.; BURNS, J. J. (1988): Maximal feeding depth of walruses. Arctic **41**, 239–240.

KASTELEIN, R. A.; GAALEN, M. A. VAN (1988): The sensitivity of the vibrissae of a Pacific walrus (*Odobenus rosmarus divergens*) Part 1. Aquatic Mammals **14**, 123–133.

KEATING, K. A.; BREWSTER, W. G.; KEY, C. H. (1990): Satellite telemetry: Performance of animal-tracking systems. J. Wildl. Manage. **55**, 160–171.

MARTIN, A. R.; SMITH, T. G. (1989): Tracking of a beluga whale using satellite telemetry. Int. Whal. Commn Paper SC/41/SM **27**, 1–11.

STEWART, B. S.; LEATHERWOOD, S.; YOCHEM, P. K.; HEIDE-JØRGENSEN, M. P. (1989): Harbor seal tracking and telemetry by satellite. Marine Mammal Sci., **5**, 361–375.

Authors' address: ERIK W. BORN and LARS ØIVIND KNUTSEN, Greenland Fisheries Research Institute, Tagensvej 135, DK-2200 Copenhagen N, Denmark